

Technology Focus: Sensors

Using Diffusion Bonding in Making Piezoelectric Actuators

Fabrication is simplified and performance improved.

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A technique for the fabrication of piezoelectric actuators that generate acceptably large forces and deflections at relatively low applied voltages involves the stacking and diffusion bonding of multiple thin piezoelectric layers coated with film electrodes. The present technique stands in contrast to an older technique in which the layers are bonded chemically, by use of urethane or epoxy agents.

The older chemical-bonding technique entails several disadvantages, including the following:

- It is difficult to apply the bonding agents to the piezoelectric layers.
- It is difficult to position the layers accurately and without making mistakes.
- There is a problem of disposal of hazardous urethane and epoxy wastes.
- The urethane and epoxy agents are nonpiezoelectric materials. As such, they contribute to the thickness of a

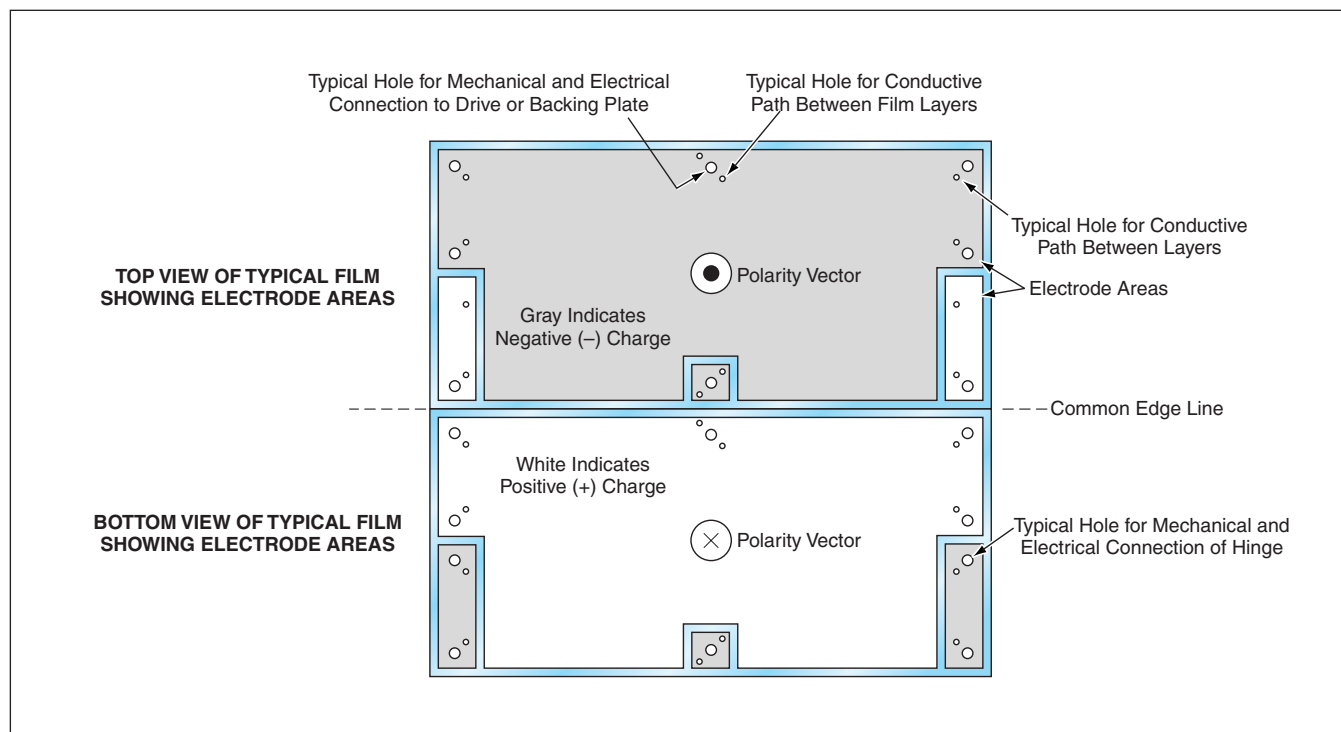
piezoelectric laminate without contributing to its performance; conversely, for a given total thickness, the performance of the laminate is below that of a unitary piezoelectric plate of the same thickness.

The figure depicts some aspects of the fabrication of a laminated piezoelectric actuator by the present diffusion-bonding technique. First, stock sheets of the piezoelectric material are inspected and tested. Next, the hole pattern shown in the figure is punched into the sheets. Alternatively, if the piezoelectric material is not a polymer, then the holes are punched in thermoplastic films. Then both faces of each punched piezoelectric sheet or thermoplastic film are coated with a silver-ink electrode material by use of a silk-screen printer. The electrode and hole patterns are designed for minimal complexity and minimal waste of material.

After a final electrical test, all the coated piezoelectric layers (or piezoelectric layers and coated thermoplastic films) are stacked in an alignment jig, which, in turn, is placed in a curved press for the diffusion-bonding process. In this process, the stack is pressed and heated at a specified curing temperature and pressure for a specified curing time. The pressure, temperature, and time depend on the piezoelectric material selected. At the end of the diffusion-bonding process, the resulting laminated piezoelectric actuator is tested to verify the adequacy of the mechanical output as a function of an applied DC voltage.

The principal advantages of the diffusion-bonding process over the older chemical-bonding process are the following:

- No adhesive thinner or hardening agent is needed;
- There are no waste chemicals;



The **Layout of Holes and Electrode Areas** on a piezoelectric layer provides for mechanical and electrical connections among stacked identical layers. The shading of electrode areas shows a typical state of charge encountered during operation. Although one layer is shown here, a prototype containing 40 such layers has been fabricated.

- Cure can be done at a relatively low temperature;
- There is less handling of piezoelectric sheets;
- No special adhesive-handling equipment is needed;
- The thickness contributed by the thermoplastic adhesive material (if used) is minimal;
- Diffusion bonding results in high-strength bonds that impart high durability and long fatigue life.
- In the case of polymeric piezoelectric layers, piezoelectric properties are improved, probably because of an increase in Young's modulus associated

with annealing during diffusion bonding.

- There is a significant reduction in electrical wiring: The electrode and hole patterns in the stacked layers give rise to an internal topology equivalent to that of a continuously folded length of piezoelectric material. As a result, the multiple electrical connections to the active piezoelectric layers are reduced to two terminal holes.

This work was done by Frank E. Sager of Oceaneering Space Systems for Johnson Space Center. Further information is contained in a TSP (see page 1).

Title to this invention, covered by U.S. Patent No. 5,761,782 has been waived under the provisions of the National Aeronautics and Space Act (42 U.S.C. 2457 (f)). Inquiries concerning licenses for its commercial development should be addressed to

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Refer to MSC-22886, volume and number of this NASA Tech Briefs issue, and the page number.

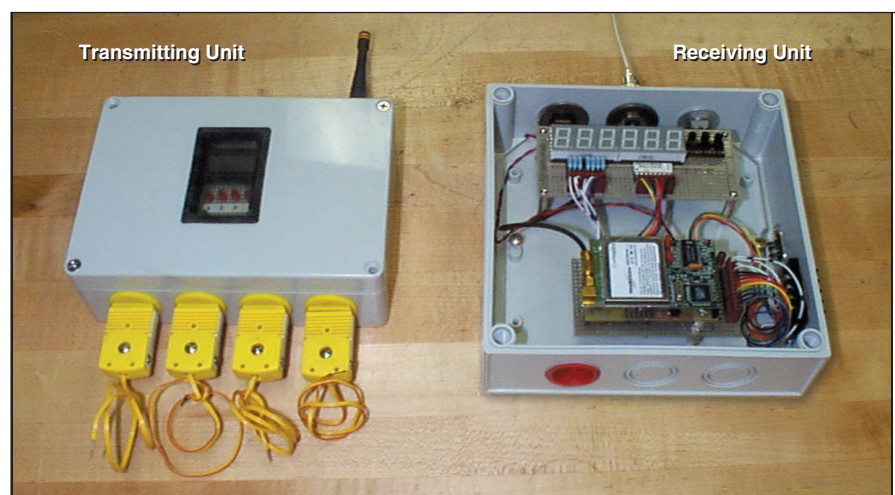
Wireless Temperature-Monitoring System

Sensors can be placed almost anywhere within 0.8 km of a receiving unit.

Stennis Space Center, Mississippi

A relatively inexpensive instrumentation system that includes units that are connected to thermocouples and that are parts of a radio-communication network has been developed to enable monitoring of temperatures at multiple locations. Because there is no need to string wires or cables for communication, the system is well suited for monitoring temperatures at remote locations and for applications in which frequent changes of monitored or monitoring locations are needed. The system can also be adapted to monitoring of slowly varying physical quantities, other than temperature, that can be transduced by solid-state electronic sensors.

The system comprises any number of transmitting units and a single receiving unit (see figure). Each transmitting unit includes connections for as many as four external thermocouples, a signal-conditioning module, a control module, and a radio-communication module. The signal-conditioning module acts as an interface between the thermocouples and the rest of the transmitting unit and includes a built-in solid ambient-temperature sensor that is in addition to the external thermocouples. The control module is a "system-on-chip" embedded processor that includes analog-to-digital converters, serial and parallel data ports, and an interface for local connection to an analog meter that is used during installation to verify correct operation. The radio-communication module contains a commercial spread-spectrum



A Transmitting Unit (One of Several) and the Receiving Unit communicate by spread-spectrum modulation at a carrier frequency near 900 MHz. The use of spread-spectrum modulation minimizes interference to other radio-communication systems.

transceiver that operates in the 900-MHz industrial, scientific, and medical (ISM) frequency band. This transceiver transmits data to the receiving unit at a rate of 19,200 baud.

The receiving unit includes a transceiver like that of a transmitting unit, plus a control module that contains a system-on-chip processor that includes serial data port for output to a computer that runs monitoring and/or control software, a parallel data port for output to a printer, and a seven-segment light-emitting-diode display.

Each transmitting unit is battery-powered and can operate for at least seven days continuously while reporting temperatures every half hour. The receiving

unit is powered by a wall-mounted transformer source. The receiving unit responds to each transmitting unit and reports the readings of each of the four thermocouples and of the ambient-temperature sensor of the transmitting unit. The end-to-end accuracy of the system is ± 0.2 °C over the temperature range from 0 to 100 °C. The radio-communication range between the receiving and transmitting units is ≈ 0.5 mile (≈ 0.8 km).

This work was done by Wanda Solano and Chuck Thurman of Stennis Space Center.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Intellectual Property Manager, Stennis Space Center; (228) 688-1929. Refer to SSC-00163.